Estimation of Comprehensive Forest Variable Sets from Multiparameter SAR data over a Large Area with Diverse Species

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ABSTRACT

Polarimetric and multifrequency data from the NASA/JPL airborne synthetic aperture radar (AIRSAR) have been used in a multitier estimation algorithm to calculate a comprehensive set of forest canopy properties including branch layer moisture and thickness, trunk density, trunk water content and diameter, trunk height, and subcanopy soil moisture. The estimation algorithm takes advantage of species-specific allometric relations, and is applied to a 100Km x 100Km area in the Canadian boreal region containing many different vegetation species types. The results show very good agreement with ground measurements taken at several focused and auxiliary study sites. This paper expands on the results reported in [1] and applies the algorithm on the regional scale.

1. BACKGROUND

Radar backscattering cross section at different frequencies and polarizations carries information about various segments of a complex vegetated surface, manisfested in different scattering mechanisms [2]. These mechanisms are (1) volume scattering from the branch and leaf layer, (2) direct ground scattering, and (3) double-bounce scattering between stems and ground or branches and ground. Volume scattering is generally best manifested in the higher-frequency, cross-polarized channels, whereas the lower-frequency, co-polarized channels are more sensitive to double-bounce mechanisms and ground scattering. However, depending on the canopy architecture, density, and moisture content, all mechanisms may enter any freqeuncy and polarization channel. Although qualitative generalization may serve to provide a preliminary understanding, quantifying such relationships for different vegetation types is not trivial.

Describing the full backscattering process requires knowledge of several vegetation variables in the branch and stem layers and soil. Since the number of available measurements is almost always fewer than the number of these vegetation variables, we use (1) mechanism-specific scattering models, and (2) allometric equations to relate variables within and between scattering mechanisms. The volume- and double-bounce algorithms developed previously [3,4], augmented with a simplified ground backscattering model are used to estimate their respective vegetation and surface variables. C-, L-, and P-band AIRSAR data from the 1994 Boreal Ecosystem-Atmosphere Study (BOREAS) field campaigns are used, along with ground measurements of the vegetation canopy at several locations. The approach consists of successively solving for unknowns to which each of the frequency bands is sensitive. First higher frequencies are used to estimate variables of the upper vegetation layer (branch and leaf layer). This information is then used, along with a numerical forest scattering model, to reduce the number of unknowns involved in the solution of the lower frequency scattering mechanisms, hence solving for unknowns in the lower layers of the canopy, e.g., stems and ground characteristics.

2. STUDY SITE AND DATA

The 100 Km x 100 Km area called the BOREAS Grid in Saskatchewan, containing 5 flux tower sites and several other well studies auxiliary sites, was covered by the AIRSAR in the summer of 1994. Portions of the same area were also covered in 1993 and 1995. Here, we will use the polarimetric C-, L-, and P-band data from July 1994, which spanned the entire grid by several consecutive flight lines, each with a swath width of 15-20 Km.

The individual flight lines were coregistered to a georeferenced species type map of the area (Figure 1), corrected for incidence angle variations across the swath, and mosaicked into a reasonably seamless image (Figure 2). At the time this summary paper was prepared, parts of the mosaic were missing due to processing delays, but the entire mosaic will be used at the presentation. The coregistration and mosaic operations were performed using the PCI software. The species type map was provided by the BOREAS staff science team, validated with ground observations, and distributed in CD-ROM format to the BOREAS investigators. The species names are omitted here due to space limitation. Allometric equations relating various vegetation variables for many of the stands in this area are also provided by one or more BOREAS investigation teams.

3. SOLUTION METHOD

The forest canopy is conceptualized as a layered medium consisting of a branch and leaf layer with a specified random collection of disks and cylinders, a trunk layer with randomly located nearly vertical cylinders that may or may not extend into the branch layer, and an underlying rough ground. Depending on the depth and scattering characteristics of each layer, different frequencies and polarizations may be used to obtain quantitative information about that layer.

The approach is to first estimate the unknowns of the top-most layer with the highest frequencies available [3]. Allometric equations for the species under study can be used to relate several parameters to reduce the number of unknowns to that suitable for estimation with the available number of data channels. With the branch and leaf layer specified, a forest scattering model, e.g., [2], can be used to simulate the backscattering contribution of the layer at lower frequencies and remove that contribution from the total measured backscattered signal. The remaining signal is due to the double-bounce and ground scattering mechanisms. Unless the canopy is very sparse or parts of the surface are exposed, there is generally very little ground backscattering contribution. The lower frequencies, such as P-band, can be used in the algorithm described in [4] to derive trunk and ground characteristics using the double-bounce mechanism. Again, the number of unknowns can be reduced by utilizing canopy-specific allometric equations.

If the ground is exposed to a degree that rough-surface scattering dominates the measurements, all frequencies can be used, each suitable for the derivation of different characteristics of the ground. Lower frequencies will be more appropriate for estimation of dielectric constant (moisture), whereas the higher frequencies will be more sensitive to roughness properties.

At each stage, the problem is stated as deriving the set of unknowns that best fits the observations given the respective polynomial scattering model. Hence, the basics of the estimation algorithm are the same in all cases. Here, we have used a nonlinear optimization technique based on an iterative preconditioned conjugate gradient algorithm. Solutions are found within a few iterations given an acceptable error condition. Depending on the unknowns involved and the data channels used for each mechanism, the associated covariances used to describe their statistical characteristics have to be carefully defined in each case. Data covariances are calculated from the AIRSAR data directly, whereas unknown variable covariances have to be assumed a priori.

5. RESULTS

Sample results of applying this procedure are shown in Figures 3 and 4. Figure 3 shows the results of the first tier for a subset of the grid, where polarimetric C-band data are used to estimate canopy height, moisture, and density. These are used to simulate the branch-layer contribution at L- and P-bands, which are then subtracted from the total SAR backscatter at these frequencies and used to calculate trunk and soil properties (Figure 4, shown for a subset of Figure 3). The results for the entire BOREAS grid, using various allometric relations, will be shown at the presentation.

REFERENCES

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ACKNOWLEDGMENT

This work was performed ~~by~~ at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, under contract from the National Aeronautics and Space Administration.

Figure 1. Landcover Map of BOREAS Grid

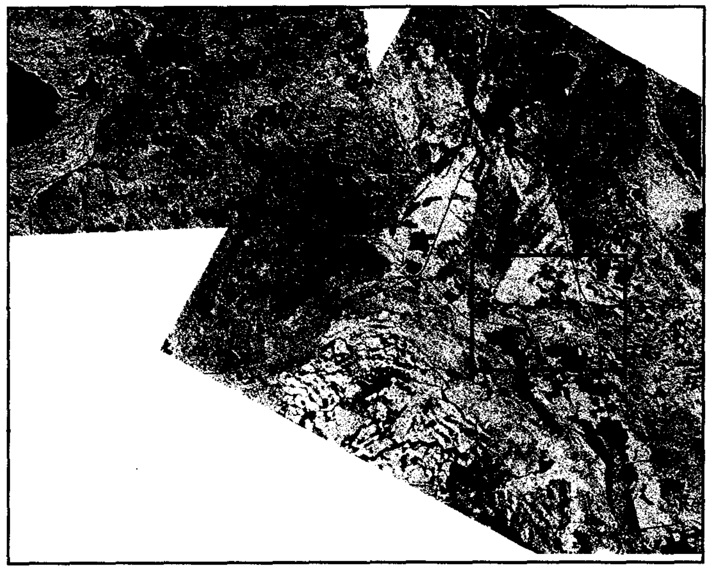

Figure 2. Partial SAR mosaic, PHH,PHV, LHH as RGB

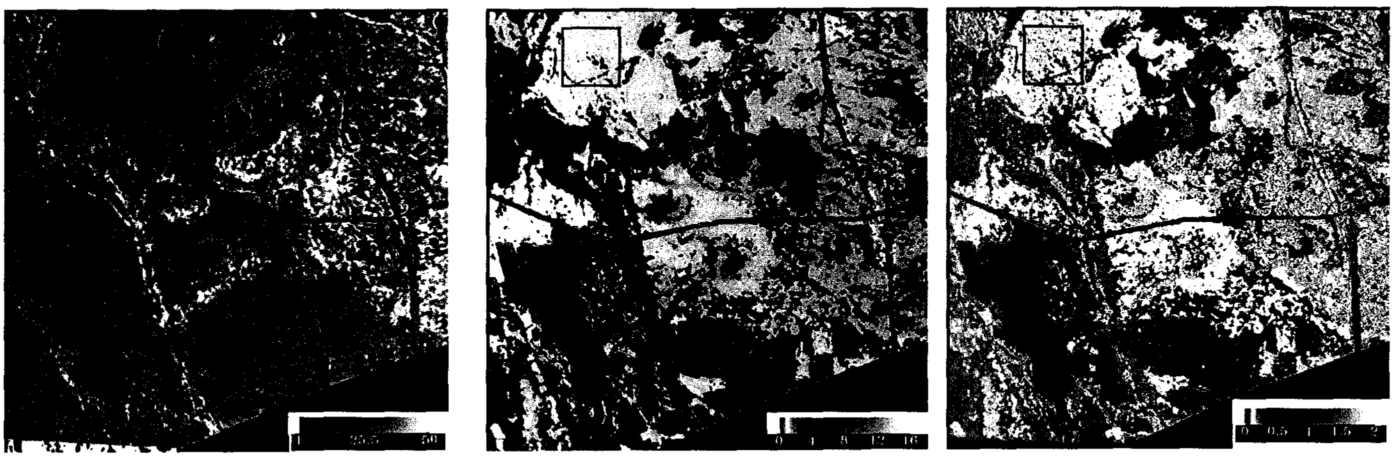

Figure 3. Left to right: Dielectric constant, height, and density of box shown in Figure 2, from C-band data.

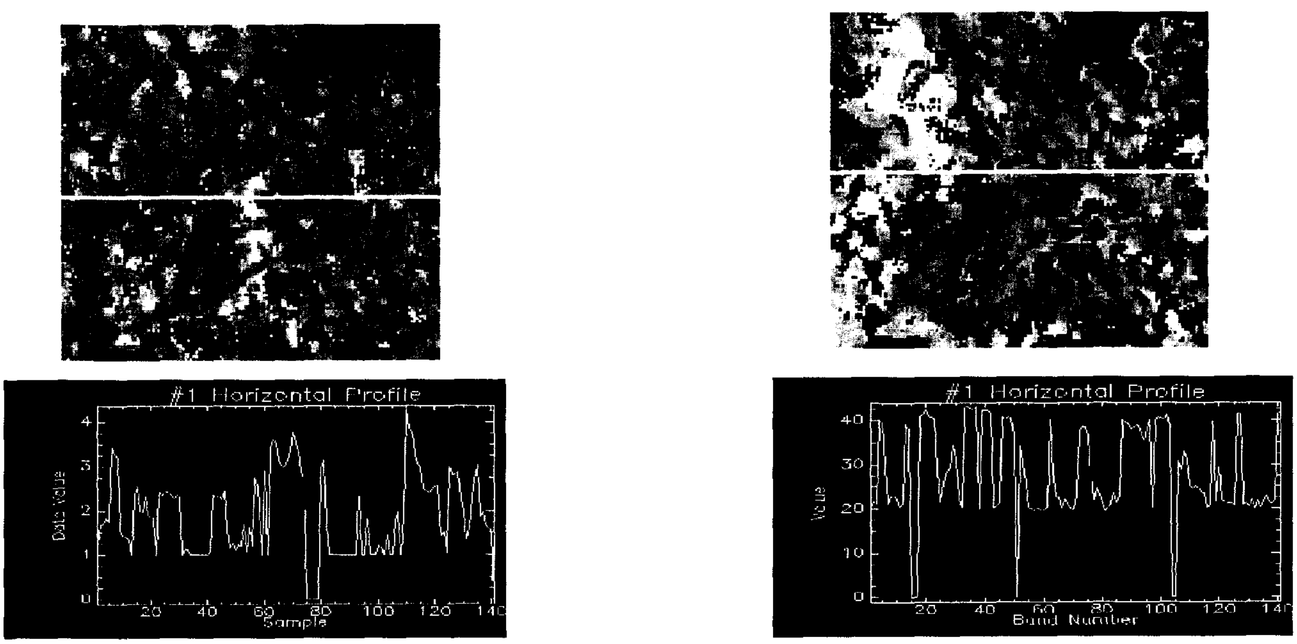

Figure 4. Left: Soil Dielectric constant and, Right: trunk dielectric constant of red box in Figure 3.